Inter-Annual Variability and Prediction of Eddies in the Gulf of Aden and the Somali Current Region

Tommy G. Jensen
International Pacific Research Center
University of Hawaii at Manoa
1680 East-West Road, POST Bldg 401
Honolulu, HI 96822
phone: (808) 956-5468 fax: (808) 956-9425 email: tjensen@hawaii.edu

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http://iprc.soest.hawaii.edu/~jensen

LONG-TERM GOALS

Understanding and quantifying the physical processes that determine air-sea interaction, currents and hydrography in the western Indian Ocean and Arabian Sea, from diurnal time scales to seasons is the overall research goal.

OBJECTIVES

The objective of the proposed research is to provide a detailed investigation of the physical aspects of eddies found in the Gulf of Aden and in the Somali Current region in the Arabian Sea. The project will quantify the physical characteristics and statistics of the eddies, including their horizontal scales, their strength with depth, influence on temperature, salinity and density, their generation and their life span.

More specifically, the objectives are

To provide a climatology and statistics of eddy fields in the Gulf of Aden based on observations from satellite altimeters and hindcast ocean models and to obtain a comprehensive understanding of the eddy generation and dynamics.

To investigate the impact of the eddies on air-sea interaction using correlation analysis between sea surface height anomalies and air-sea fluxes.

To determine the predictability of eddy fields from observations and numerical models.

APPROACH

The questions above will be addressed relying on primarily on two key sources of information. We propose to analyze sea surface height from combined TOPEX/Poseidon, ERS and Jason altimeter data set and the output from state-of-the-art models to investigate the inter-annual variability of Gulf of Aden eddies and the mechanisms that generate them. SSH from T/P altimeter is the best source for high-resolution observations of the eddy fields and OGCM runs can be used for a detailed 3-D analysis of eddy dynamics and their impact on SST, upwelling and vertical density structure. Output with a 3-day frequency is available from the Ocean model For the Earth Simulator (OFES) hindcast run forced

with NCEP re-analysis (1950 – 2005). This data is already available at the International Pacific Research Center (IPRC) at University of Hawaii. Nowcast/forecast runs from the Naval Research Laboratory using HYCOM is available for selected periods from Jan 2003 until present from COAPS, FSU.

These data sources will be supplemented using observational data sets (Table 1 below) to determine an impact of eddies on air-sea interaction. In particular, it is anticipated that negative SST anomalies associated with cyclonic eddy activity may suppress mixing in the planetary boundary layer and weakening the surface wind as a result. Conversely, the relatively higher SST in anti-cyclonic eddies tend to increase the depth of the planetary boundary layer and locally increase the near surface wind speeds and the latent heat flux. AVHRR SST and QuickScat winds will be used for this analysis.

For additional analysis and for evaluation of eddy predictability model output from eddy resolving layer models (NLOM) from the Naval Research Laboratory at Stennis Space Center will be used. The NRL NLOM have routinely been run in nowcast mode and forecast mode after assimilation of data and the output is available for analysis at the IPRC. Details are given in Table 2 below.

Observational Data Sets

Most available observational data sets are too limited in spatial and temporal resolution to adequately resolve eddies along the Arabian Peninsula. This is in particular true for air-sea heat flux data sets. The following data sets will be used for analysis:

TABLE 1

Observed Data set	Resolution	Time span	Variables
TOPEX/Poseidon/ERS/Jason1 combined altimeter data	0.25^{o}, weekly	10/92 - 6/03	SSHA
AVHRR Pathfinder v.5	4 km, daily	1985-2004	SST
WHOI OA heatflux	1.0 ^{o}, daily	1/81 -12/02	LH, SH
ISCCP	1.0 ^{o}, daily	1/81 -12/02	Net SW, net LW
Quickscat	0.25 ^{o}, 3 day	7/99-01/06	TX,TY
SeaWIFS	0.25 ^{o}, weekly	10/97-11/05	chlorophyll

These data sets have relatively high spatial and temporal resolution necessary to resolve the eddies. An exception is the ISCCP radiation data. This data has been interpolated to the same grid as the WHOI objectively analyzed heat flux data from a resolution of 2.5 ^{o}

The latter data sets as well as Quickscat will be used to investigate possible air-sea interaction over the eddies. The SeaWIFS data will only be used to help identify upwelling regions.

Monthly eddy climatology and inter-annual variability

The eddies drift westward along the Arabian coast so it is useful first to establish maps that show their monthly positions. Preliminary examination of high resolution model output from inter-annual runs indicates that several eddies appear in the same locations each year although year to year variability

can be large. Therefore a monthly climatology will be established and year-to-year variations and climate extremes will be studied.

The manifestation of eddies is most significant in sea surface elevation so the first step is to produce maps of sea surface heights. Observed sea level heights will be computed from a combined weekly sea surface height anomaly (SSHA) from TOPEX Poseidon, ERS and Jason1 satellites. This data is mapped on a global irregular grid with $1/3^o$ spacing on average. Data is available from October 1992 to June 2003. There is variability from year to year so maps of monthly variance will also be produced.

From the observed SSH fields the barotropic part of the geostrophic currents will be computed and compared with model results from OFES and HYCOM.

Other observed quantities with high resolution are difficult to obtain, in particular sub-surface quantities, so the project will rely on model simulations for variables other than SSH and SST. The following model data sets will be used:

Model	Resolution	Time of data	Variables
OFES 50yr run Climatology forcing	0.1^o , 54 levels	Last 8 years Daily output	SSH, u,v,w,T,S (3d)
OFES hindcast	0.1^o , 54 levels	Jan 1950 - Dec 2004 Monthly	SSH, SST
HYCOM nowcast	$1/12^o$, 32 layers	Apr 2007 - present	SSH,u,v,T,S (3d)
HYCOM hindcast	$1/12^o$, 32 layers	Nov 2003-Dec 2004	SSH,u,v,T,S (3d)
HYCOM simulation	$1/12^o$, 32 layers	Jan 2003-Dec 2005	SSH,u,v,T,S (3d)
NLOM nowcast	$1/32^o$, 6 layers	Apr 28, 2005 - now	SSH, SST, u,v at surface
NLOM nowcast	$1/16^o$, 6 layers	Jun 2002 -Mar 2006	SSH, SST, u,v at surface

The Ocean Model for the Earth simulator is a full Ocean General Circulation Model and output from this model will be analyzed in most detail. The main advantage of the NRL NLOM model output is the higher horizontal resolution which may give different eddy characteristics and statistics than OFES or T/P SSH. In that case there is a possibility that the resolution of the observed SSH is inadequate.

Eddy Characteristics

The eddy scales will be determined from the data and models above. This includes eddy diameter, current speed, propagation speed and variation with depth.

The associated changes in temperature, salinity and density will be computed for a large number of eddies. Correlation of eddy scales between observations (SSH and derived barotropic geostrophic velocities) and model variables will be computed.

Generation mechanisms

The main hypothesis is that the eddies along the southern shore of the Arabian Peninsula primarily are generated by remotely forced Rossby waves. Along the west coast of India the wind generates upwelling and downwelling patterns, which result in Rossby wave radiation across the Arabian Sea (Jensen; 1991). This Rossby wave radiation was later confirmed by SSH observations from Topex/Poseidon (Brandt et al, 2002). A competing mechanism during the southwest monsoon is an extension of the Somali Current through the gap between the island of Socotra and the Horn of Africa which may drive eddy flow in the entrance to the Gulf of Aden.

Prediction

The remote forcing leads to a potential for forecasting the eddy field. It is proposed to produce correlation maps between SSH anomalies for a number of locations near 65^{o}E with latitudes ranging from 10^{o}N to 22^{o}N using the T/P-ERS data set. The same calculation will be computed for the OFES and NRL models. A comparison between the NRL nowcast model and the NRL forecast model output will reveal if successful forecasting of eddies can be done with an operational model.

WORK COMPLETED

The project started in August 2007. A monthly climatology of SSH anomaly relative to the 1993-2003 mean were completed for the Topex/Poseidon/Jason composite product. Monthly SSH climatologies from two runs with OFES were also completed. One is forced by a monthly NCEP/NCAR reanalysis climatology (e.g. Kalnay et al., 1996) based on the years 1950 to 1999 and spun up for 50 years. The SSH anomaly climatology is computed using the last 6 years of this spin-up run. Details of the model and the forcing are given by Matsumoto et al (2004). The second model run is a hindcast of OFES (Sasaki et al., 2007) using the first run as initialization. This model is forced by daily NCEP/NCAR reanalysis fluxes from 1950 to 2006, and the SSH analysis cover the same period as the TOPEX/Poseidon data.

A comparison between TOPEX/Poseidon altimeter data and surface elevation (SSH) from OFES has been done for the Somali Current region. Eddy statistics, eddy potential energy (EPE), and spectral characteristics are compared over the area from the equator to 18^{o}N between 40^{o}E – 60^{o}E.

RESULTS

The OFES model hindcast run is in very good agreement with TOPEX/Poseidon climatology and is superior to OFES results from the spin-up run with climatological forcing. This implies that inter-annual variations in the forcing and/or high-frequency forcing have a significant impact on the circulation. The most important results is that a difference in variance between the climatological OFES run and the hindcast run reveals that 60% of the SSH variance is due to internal variability of the flow. Figure 1 below show an example of the good agreement for EPE computed for August. The three local maxima in EPE associated with the Great Whirl seen in the observations is simulated well in the hindcast, but is absent in the run forced by monthly climatology. The agreement between OFES and T/P satellite data is typical for monthly maps of EPE, but the best agreement is found during the height of the monsoon seasons.

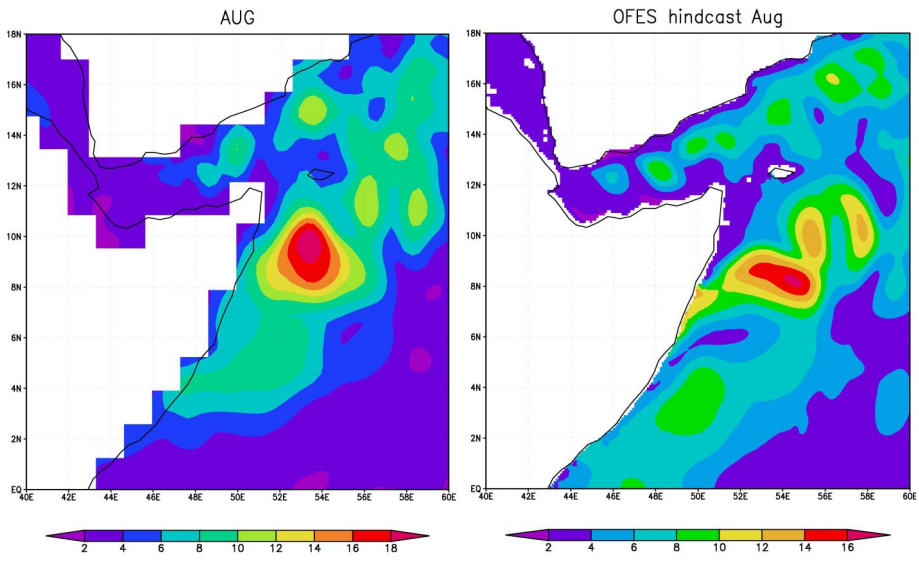

Figure 1. Eddy Potential Energy(EPE) for August. Overall good agreement between EPE for the Great Whirl and associated eddies is found between the monthly climatology from TOPEX/Poseidon (left) and from the OFES hindcast (right).

IMPACT/APPLICATIONS

The Gulf of Aden is important for the world economy. It is one of the most active shipping lanes in the world, connecting the Indian Ocean to the Suez Canal. Nearly 3 million barrels of oil are transported through the Gulf of Aden daily. In addition, Yemen currently exports 350 to 370,000 barrels per day of crude oil through the terminals at Ras Isa and Ash Shihr. To the south near the island of Socotra and near the Somali coast shipping is exposed to attacks from pirates. It is expected that a better knowledge of the currents, in particular the seasonal changes of the energetic mesoscale eddies in Gulf of Aden, will be useful for naval ship operations, search and rescue and control of oil spills in this important geographic area.

RELATED PROJECTS

There are no related projects.

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